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RADC-TR-68-592  
28 October 1968



**SECOND SOURCE FOR CROSSED-FIELD AMPLIFIER  
QKS1567 C-BAND SELF-MODULATED FORWARD-WAVE AMPLIFIER**

Peter Laurendeau

Richard Handy

Contractor: Raytheon Company  
Contract Number: F30602-68-C-0291  
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Contract Expiration Date: April 1969  
Amount of Contract: \$122,000  
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**Raytheon Company**

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## FOREWORD

This study is being performed at Raytheon Company's Microwave Tube Operation, a component of the Microwave and Power Tube Division, Waltham, Massachusetts, for the Advanced Research Projects Agency, Washington, D. C. Rome Air Development Center, Griffiss Air Force Base, New York, is monitoring the study for ARPA, under AF Contract F30602-68-C-0291. Mr. Dirk T. Bussey, EMATE, is the RADC Project Engineer.

Overall responsibility is borne by the Crossed-Field Amplifier Group, John F. Skowron, Manager. The mechanical and electrical design of the experimental models is performed by Peter Laurendeau, Senior Engineer, under the direction of Richard A. Handy, Engineering Section Manager.

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This Technical Report have been reviewed and is approved.

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## ABSTRACT

The main objective of this program is to develop a self-modulated forward-wave crossed-field amplifier at C-band with higher peak and average power capability than has been realized in the past. Tube performance objectives are 2 MW peak, 20 kW average, 50 microsecond pulse duration in C-band with 10% instantaneous bandwidth. During this report period, the tube mechanical design was completed. All tube parts were ordered and received. Approximately 50% of a complete tube assembly was built. Anode model no. 1 was brazed and cold test measurements were obtained.

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## 1.0 INTRODUCTION

This crossed-field amplifier development program is authorized by RADC contract No. F30602-68-C-0291. The new CFA will bear the Raytheon designation QKS1567. The prime objective of this program is to achieve CFA operation at a power output level of 2 MW peak power, 20 kW average power at 50 microseconds pulse duration. Such an amplifier will provide considerably higher performance capability than has been realized in the past. The tube is also to be developed to provide self-modulation, that is, full keying of the tube current on and off by the rf drive signal alone, with dc operating voltage continuously applied. The tube will be designed to operate at C-band over a 500 MHz band with 10 to 13 dB minimum gain at a single value of dc voltage.

Breadboard QKS1567 operating models are being built incorporating a stub-supported double helix line anode structure (SSDHL). The main feature of the SSDHL circuit is its anode height which is greater than that of anode circuits previously used for CFA operation.

Impedance matching circuit design of the SSDHL has been completed on cold test for anode model no. 1. The final matching design incorporates waveguide ramps positioned parallel to the tube magnetic field lines of flux to avoid multipactor.

The cathode assembly is almost complete. Liquid-cooled emitting surfaces of platinum and beryllium will be tried. The bias electrode will also be liquid-cooled and will have a surface configuration design to inhibit secondary emission.

## 2.0 ANODE CIRCUIT DEVELOPMENT

Cold test data reported in the first interim report is shown in Figure 1, curve A. The linear cold test circuit employed 10 active sections to obtain dispersion curve measurements. Careful investigation revealed that the stub-supported double-helix circuit possibly propagated as two independent circuits above approximately 120° phase shift per section. Using a small number of active sections (such as 10) one can easily measure each resonance and determine its exact phase shift. Above 120° phase shift, extra resonances appeared for a 10 section circuit, indicating that perhaps the circuit was propagating in two separate paths due to the use of two helices. Previous cold test studies on a single stub-supported helix confirmed these findings, showing the correct number of resonances and proper performance.

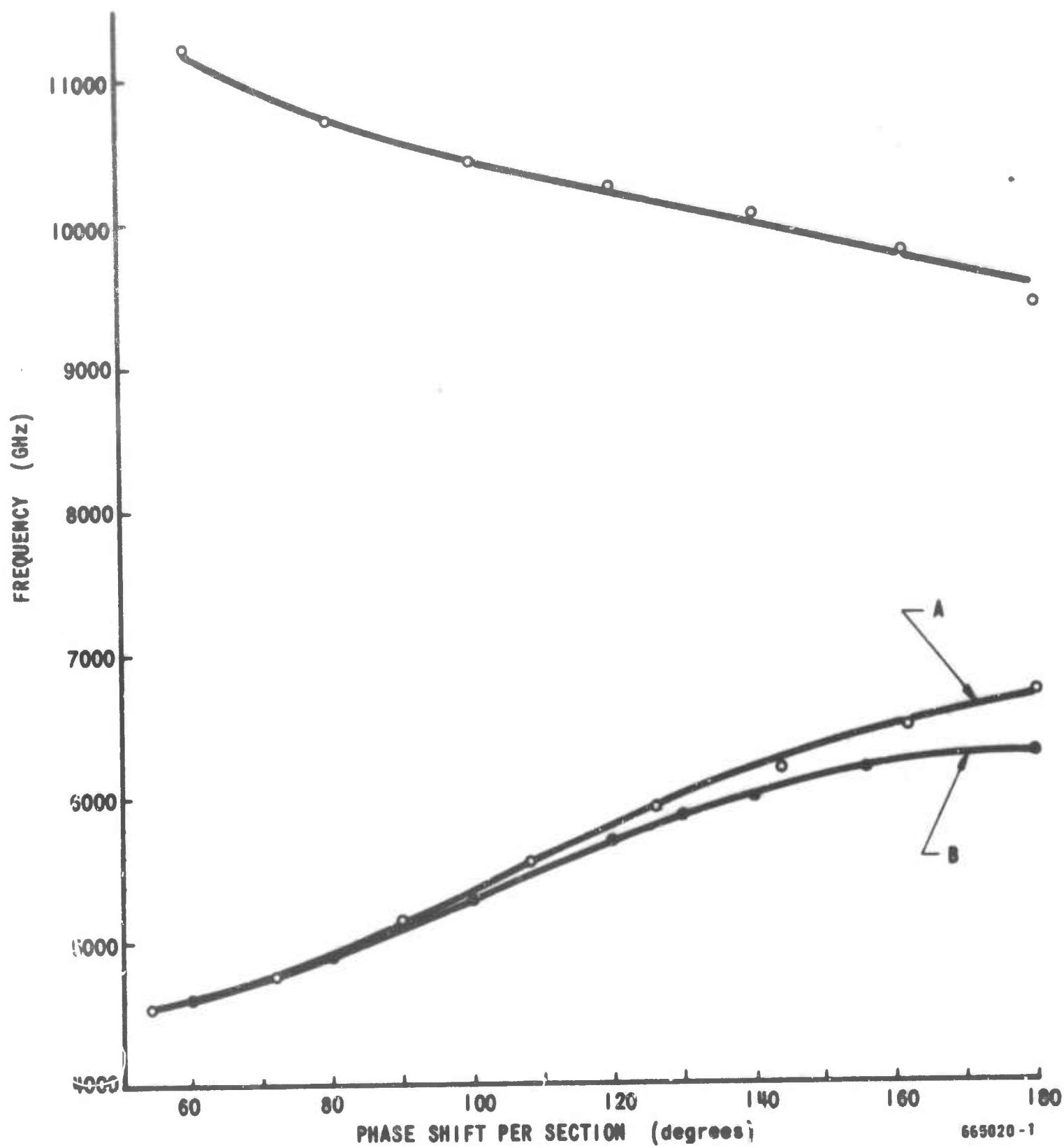


Figure 1. QK1567 C-Band Dispersion Curve

A redesign of the SSDHL circuit was necessary to assure a single dispersion curve. A change in helix turn spacing and vane tip thickness resulted in a circuit which had more vane tip loading and a reduction in the helix mutual inductance. This change resulted in a single dispersion curve and a narrowed bandwidth circuit as shown in Figure 1, curve B. Over the operating band (5.425 GHz to 5.925 GHz) the phase shift per section varies from 102° to 133°. The upper frequency cutoff (180°) was lowered from 6.8 GHz to 6.35 GHz.

Our previous experience in backward-wave CFA's has shown that there is a coupling of energy between the backwall (anode body) and the SSDHL circuit. An expedient cure has been the use of screws selectively mounted on the backwall (anode body) adjusted to tune the various backwall resonances outside the operating band. The presence of the resonances on hot test will produce a noisy spectrum whenever the CFA is operated at the same frequency as the backwall resonance. The screws tend to lower the frequency of the resonance out of the operating band and the position of the screws along the backwall circumference prevents the lowering of other resonances into the operating band.

To completely eliminate backwall resonances it is necessary to make the enclosed region between the circuit and backwall short enough to raise its low frequency cut-off above the operating frequency of the CFA. Due to the large anode height of this tube and the ridge effect of the helix, it is extremely difficult to raise the low frequency cut-off above the operating band. In the QKS1567 case, however, the backwall region was made as small as possible without affecting the high frequency cut-off of the SSDHL circuit. This design change improved the overall impedance match of the circuit and has apparently reduced coupling to the backwall region to an acceptable level.

Figure 2 shows a cross section of the anode assembly, including the added backwall cover. Another mechanical design feature of this anode is the use of C-shaped vanes which reduces the overall height of the backwall region and helps to increase the low frequency cut-off. C-shaped vanes are also advantageous as they minimize thermal expansion problems and avoid anode distortion. As Figure 2 shows, the C-shaped vanes provide enough clearance to permit the cathode end shields to cover the entire interaction area, minimizing space charge leakage to the pole piece, especially in the bias electrode region where the space charge breaks up and tends to spread axially. The end shields are well thermally-cooled in the bias electrode region to avoid excessive electron bombardment heating.

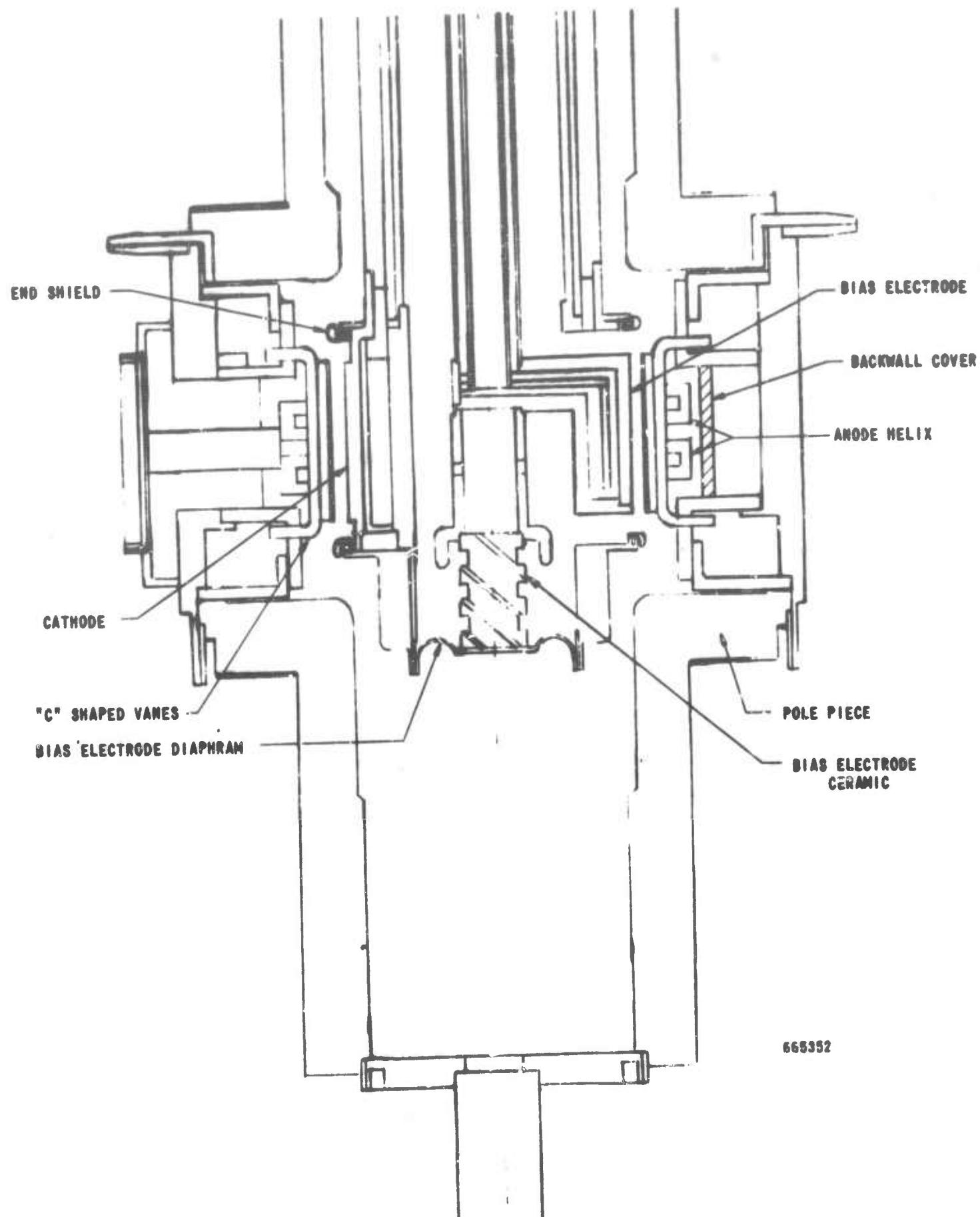


Figure 2. QKS1567 Anode Assembly Cross Section (Partial)

Figure 3 shows the brazed anode model no. 1 assembly with the added backwall removed to show the helices. Figure 4 is a photograph of a one-piece 3/4 turn machined helix part which will be used in building anode model no. 2. When this part is brazed to the anode-vane tubing, the helix turns are completed. The copper supporting ring will be machined off and the separated helix turns supported by the anode vanes.

### 3.0 CATHODE DESIGN

A cross section of the cathode is shown in Figure 2. The liquid-cooled bias electrode has a ceramic support which is located beyond the cathode area to prevent any metallic deposit from the interaction area from coating the ceramic surface and eventually leading to shorting the bias electrode to the main cathode.

Differential expansion between the bias electrode and the cathode assemblies has been accommodated by the use of a cupro-nickel diaphragm which supports the bias electrode radially, permitting any necessary axial movement.

The molybdenum end shields are brazed to a copper support which is liquid cooled.

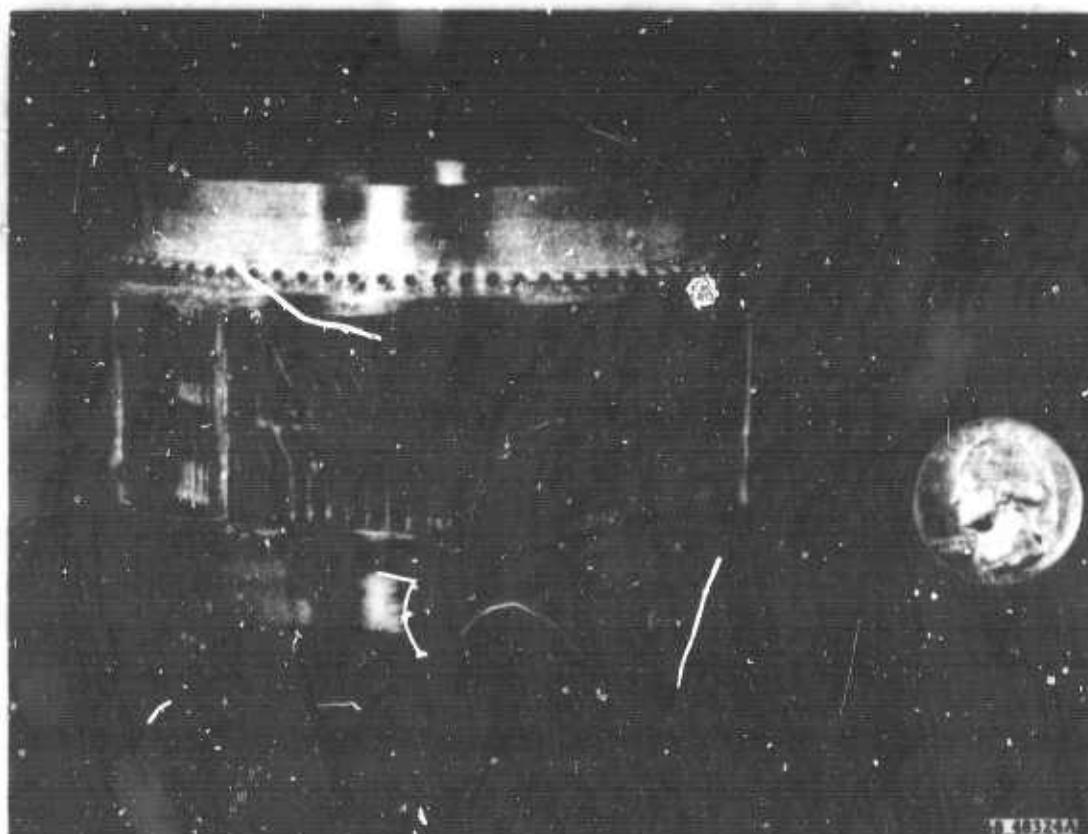
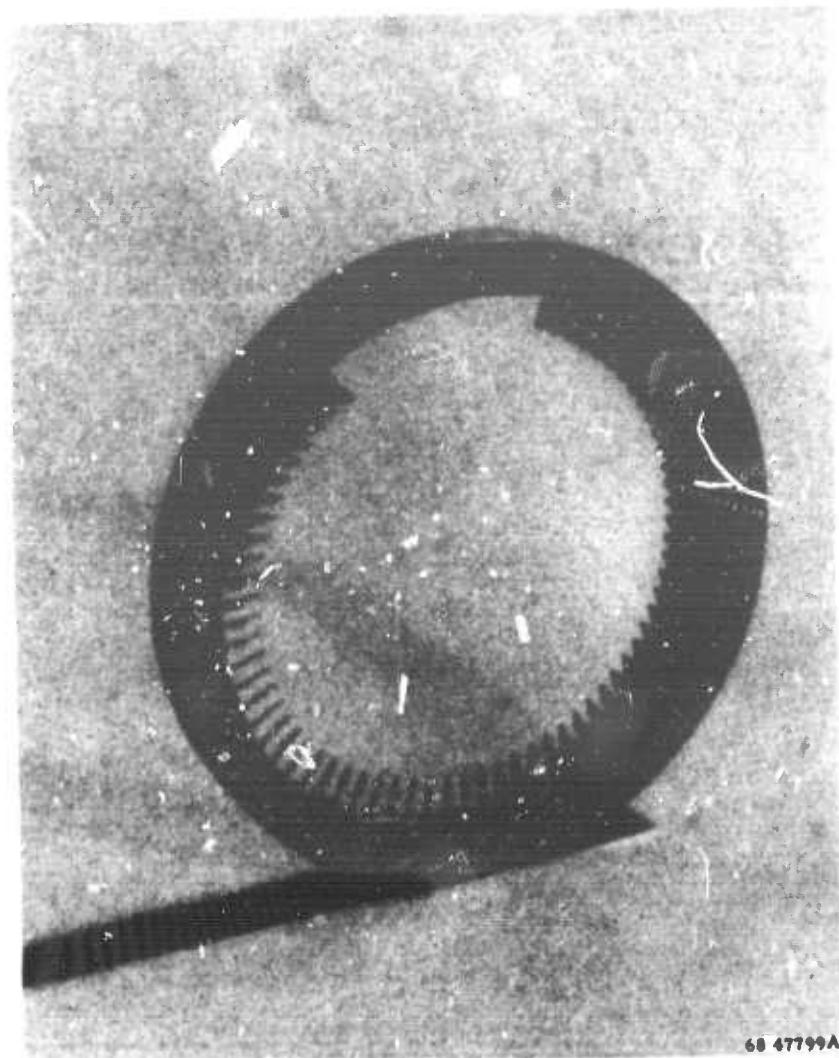


Figure 3. Brazed Anode Model No. 1 Assembly with Added Backwall Removed.



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**Figure 4. One-piece 3/4 Turn Machined Helix Supported by a Solid Copper Ring**

#### 4.0 ANODE MODEL NO. 1 COLD TESTING

All cold test measurements were made on anode model no. 1 after brazing of the helix vane assemblies to the water jacket. The waveguide-to-anode ramp connecting the SSDHL circuit to the waveguide transformer was assembled using silver paint permitting cold test evaluation of the entire tube prior to a final braze of anode to waveguide. After the final tube braze, access to the ramps will be possible to provide some limited final impedance match adjustment.

Figures 5 and 6 show the impedance match of anode model no. 1 for the input and the output ports.

Impedance matching work was concentrated over the operating band and beyond up to 180° phase shift per section ( $\pi$ -mode). For proper dc operation, a bias electrode CFA requires that any resonances above the operating band up to the high frequency cutoff ( $\pi$ -mode) of the SSDHL circuit be matched so as to prevent the CFA from oscillating.

Insertion loss measurements are as shown in Figure 7. The insertion loss is somewhat higher than anticipated and could possibly be due to the following: silver paint used for ramp connection, eutectic brazing solder covering most of the SSDHL circuit area (eutectic solder has a higher skin resistance than copper), molybdenum vane tips, and roughness of the circuit. The insertion loss of a lower power level C-band CFA (QKS1480) (84 sections) stub-supported meander line also had an insertion loss averaging 4 to 5 dB.

#### 5.0 SUMMARY

Over 50% of the tube has been built; we expect to complete tube seal-in by the next report period.

Impedance matching work will be pursued further on anode model no. 2. The next brazed anode should have a more uniform structure, benefiting from the experience gained in assembling the first anode.

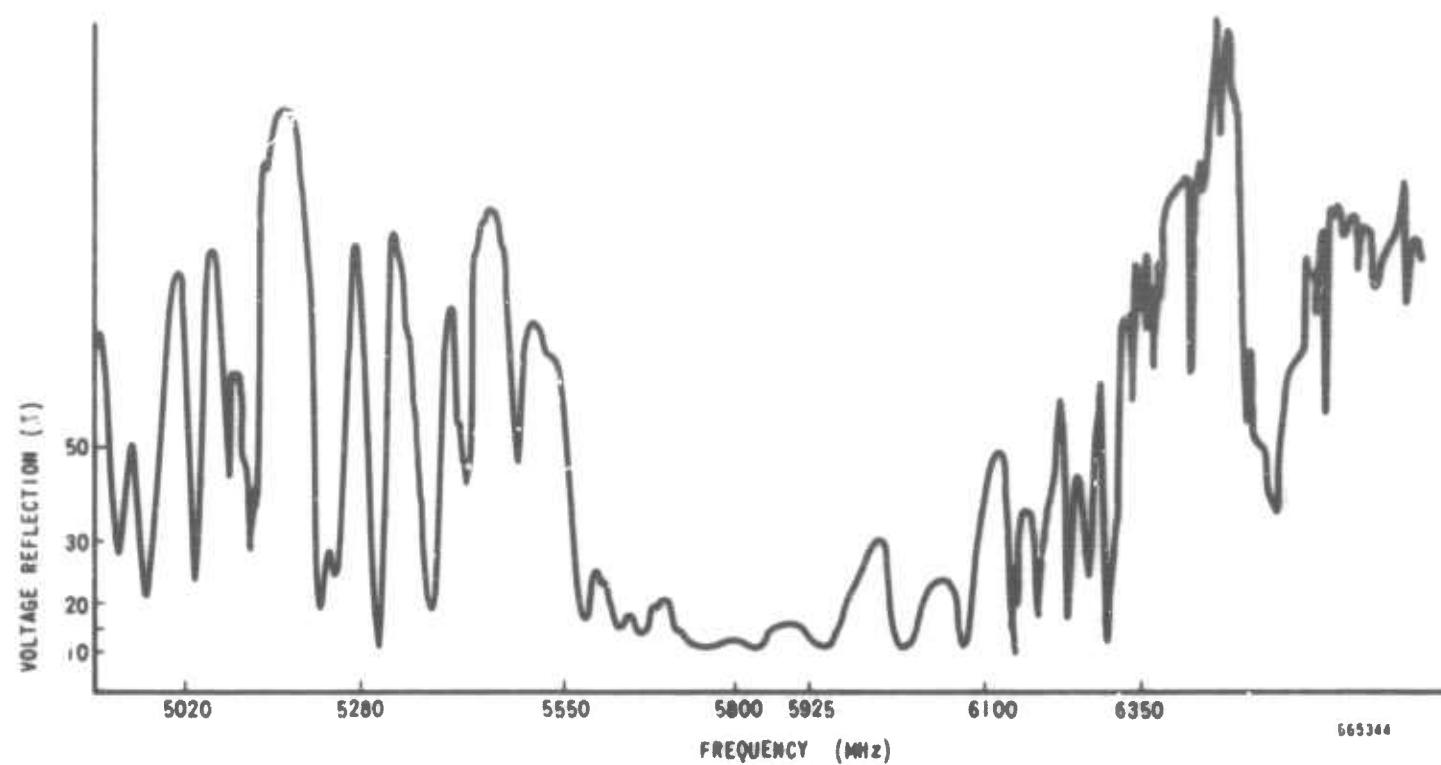


Figure 5. QK1567 Impedance Match Anode Model  
No. 1 Input Port

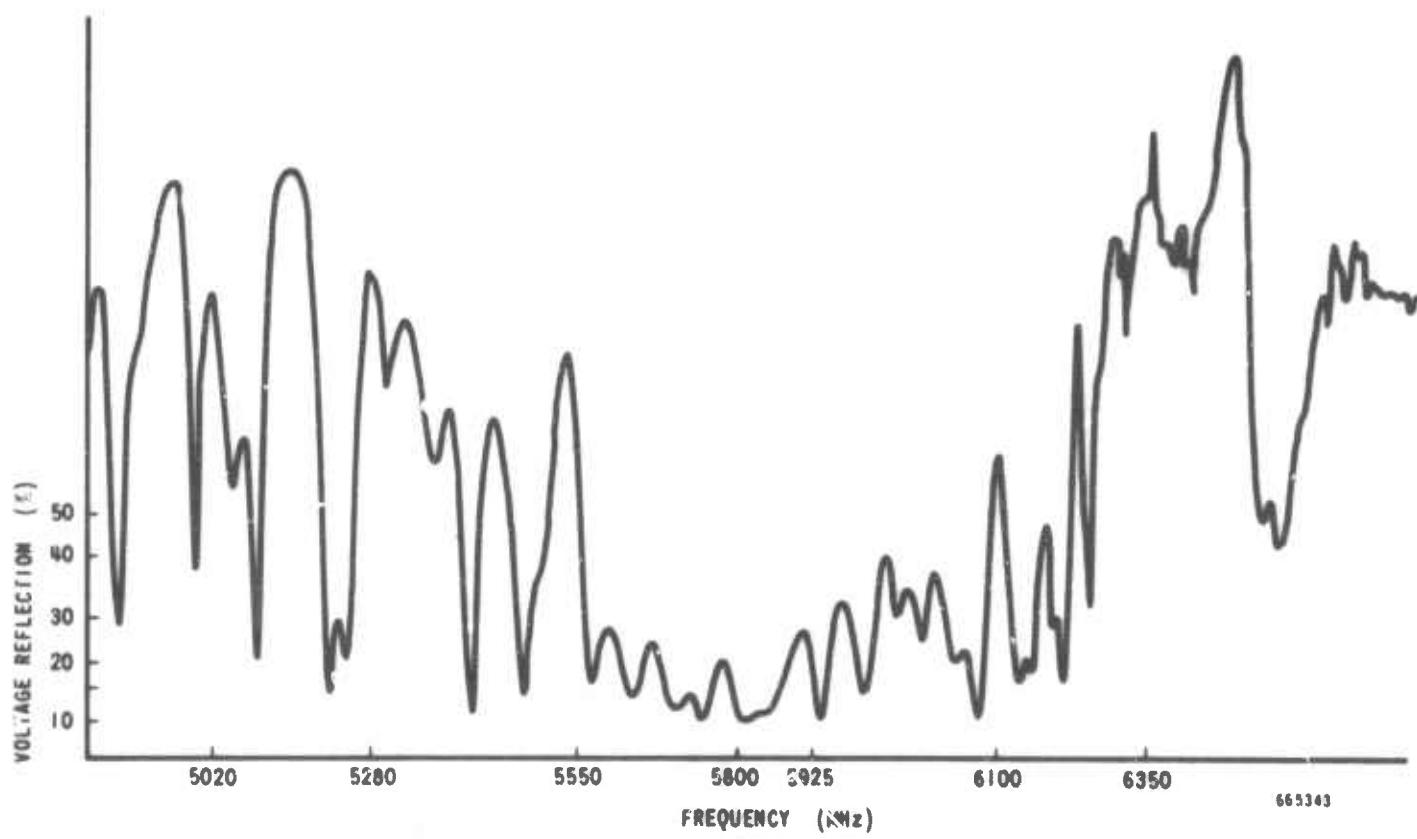


Figure 6. QK1567 Impedance Match Anode Model  
No. 1 Output Port.

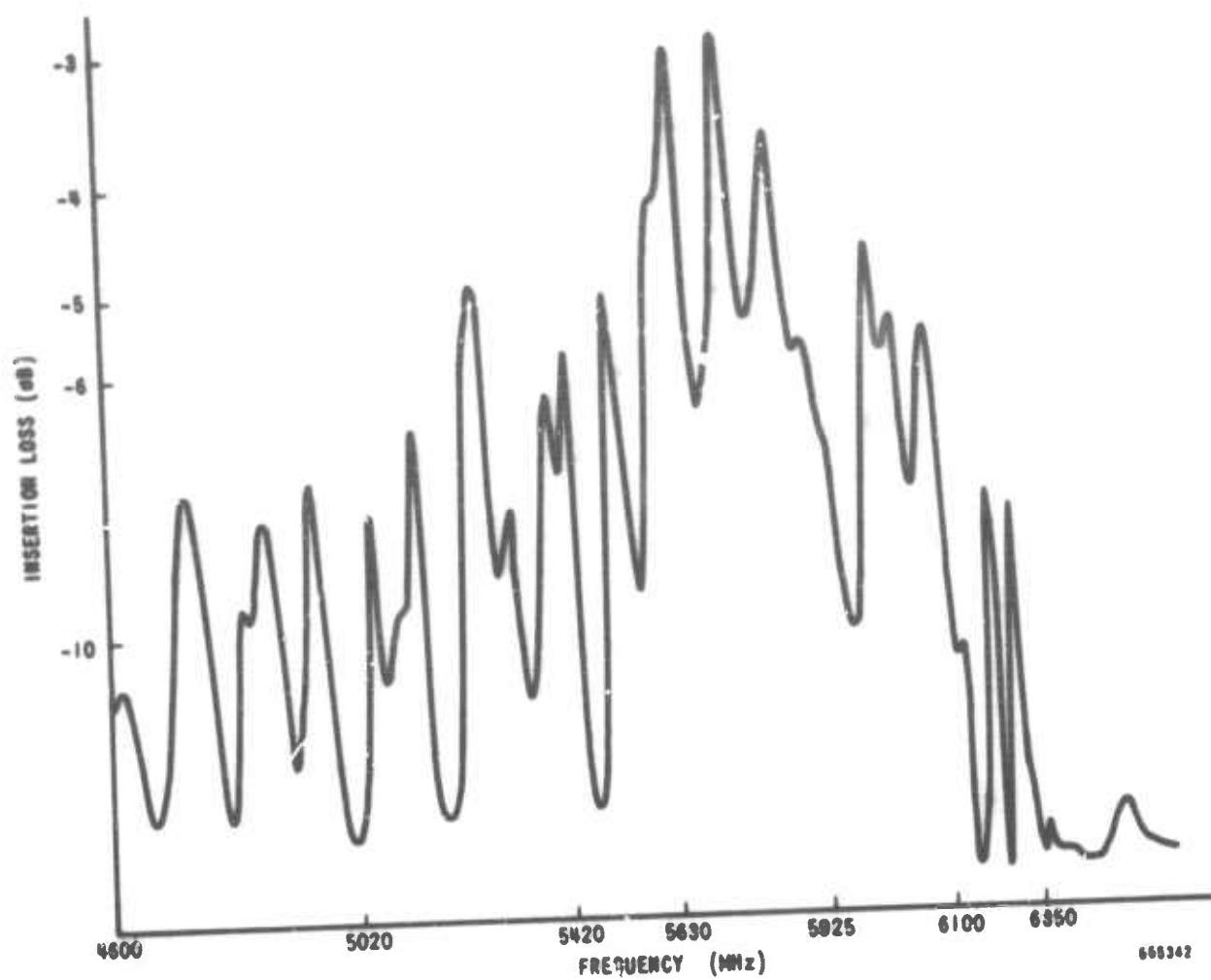


Figure 7. QK1567 Insertion Loss Anode Model No. 1

## 6.0 PLANS FOR THE NEXT PERIOD

1. Complete tube model no. 1.
2. Start construction of tube model no. 2.
3. Improve impedance match of anode model no. 2.

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13. ABSTRACT

The main objective of this program is to develop a self-modulated forward-wave crossed-field amplifier at C-band with higher peak and average power capability than has been realized in the past. Tube performance objectives are 2 MW peak, 20 kW average, 50 microsecond pulse duration in C-band with 10% instantaneous bandwidth. During this report period, the tube mechanical design was completed. All tube parts were ordered and received. Approximately 50% of a complete tube assembly was built. Anode model no. 1 was brazed and cold test measurements were obtained.

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